LDSP: Shopping with Cryptocurrency Privately and Quickly under Leadership

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Shopping with Cryptocurrency?

☹️ Slow

- Bitcoins takes 10 mins to include a payment transaction
- (~60 mins to confirm)

☹️ Low Privacy

- All transactions are exposed on the blockchain

Traditional Layer-2 Networks

- 😁 Low-latency Payment
  - Payer & payee confirm their payment "locally" (off-chain)
    - jointly-sign a balance sheet of their (updating) asset & sync "on-chain" later
- ☹️ High collateral: money locked (mostly) for a *single* payee
- ☹️ Constantly-Online Requirement
  - Payers & payees need to monitor the on-chain transactions
    - worry that the other party might upload an "outdated" balance sheet
- ☹️ (Still) Low Privacy
  - The final balance sheet is exposed on the blockchain
    - total transaction amount & who paid to whom are leaked

LIGHTNING NETWORK

Snappy: Layer-2 Solution for Retail

- *Unidirectional* system tailored for *retail* payments [NDSS 20]
  - Users take the role of either customer/payer or merchant/payee
- 😁 Low-latency Payment Solution (~ layer-2)
- 😁 Offline Customer (no need to monitor on-chain)
  - Merchant has disincentive in uploading outdated sheet
    - Penalty from their collaterals
- 😁 Low Collaterals
  - Customer collateral is "shared" among all merchants in Snappy

Shortcomings of Snappy

☹️ No Privacy (Merchants share all Payer Spending Histories)

- State = all payer's spending histories
- Merchants also serve as statekeepers
- Confirmation needs 51% of merchants to vouch
  - Each checks the balance of the payer
  - pays back from their collateral if vouched wrongly
    - e.g., a double-spending transaction

LDSP: Layer-2 Anonymous Payment

😁 **L**ow Latency

- Speedy confirmation of off-chain payment within *seconds*

😁 **D**ynamic and Distributed Setup

- Merchants (payees) can join and leave dynamically
- Customers (payers) can pay multiple merchants

😁 **S**calable On-chain Processes

- Our design naturally supports batching to *reduce on-chain costs*

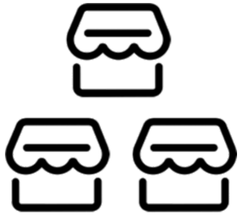
😁 **P**rivacy

- Customers (payers) can hide their identities
- They can "hide in the crowd" to obfuscate the payment amount

Core Entities in LDSP

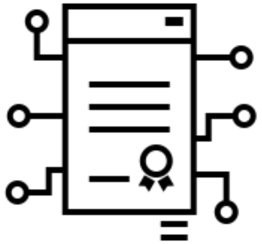
- Customers, who want to pay merchants (off-chain)

- A consortium, formed by a group of merchants



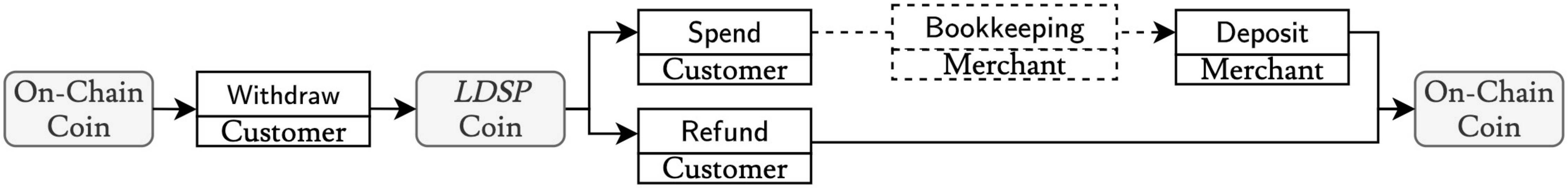
- A *leader*, leading the consortium

- An arbiter (smart contract), for resolving disputes, *etc*.



Workflow (& Core Functions)

1. Customers *withdraw* LDSP coins by funding them on-chain
2. Customers *spend* (off-chain) LDSP coins to a merchant
3. Customers *refund* unspent LDSP coins
4. Merchants *bookkeep* and *deposit* the received LDSP coins to receive the on-chain coins (funded by customers)



Dilemma: Who issue LDSP coins?

- All merchants (or statekeepers) are needed to issue coins
  - Not scalable!
- Only 1 merchant (or statekeeper) is needed to issue coins
  - Keep issuing coins to a "customer" to be spent at victim merchant
  - Becomes a money-printing factory!
- A large subset of them needed to issue coins
  - The worst of both worlds?
  - Need many to help, but they can still collude
  - Or is it?

High-Level Operations of LDSP

- We introduce *leaders,* each leads a group of merchants
- Merchants in a group jointly issue coins, forming a "*virtual bank*"
- A coin can either be spent with the issuing merchant
- or at another merchant, which we call cross-group payments

Leader’s Duties and Motivation

- settles w/ other leaders for cross-group payments
- confirms payment (in its group) to avoid double-spending
- motivations: getting service fees, establishing partnerships

Highlights of LDSP

- Small group size, which mitigates the scalability problem
- State = which merchant gets back how many LDSP coins
  - Formed by "consensus" between the leaders and the merchants
- Merchants can belong to different "virtual banks"
  - *i.e.*, the groups forming the banks are *overlapping*
- Merchants, who are payees, have no incentive to forge

Design Intuition (Merchant Perspective)

- Self-evolving ecosystem
- We leverage the "business relationship" among merchants to help their beloved customers.
- Somewhat like how inter-bank transactions are cleared
  - *"I know this virtual bank well. I'll just accept its coins."*
  - *"I'm not familiar with this bank. Let me talk to them first before accepting too many coins issued by them."*

Design Intuition (Customer Perspective)

- Somewhat similar to customer-loyalty programs
- Think of the coins are the "points"/"mileages"

- *"I frequent these shops. Let me get more coins from them."*
- *"I may occasionally buy this each month. I'll get less here."*

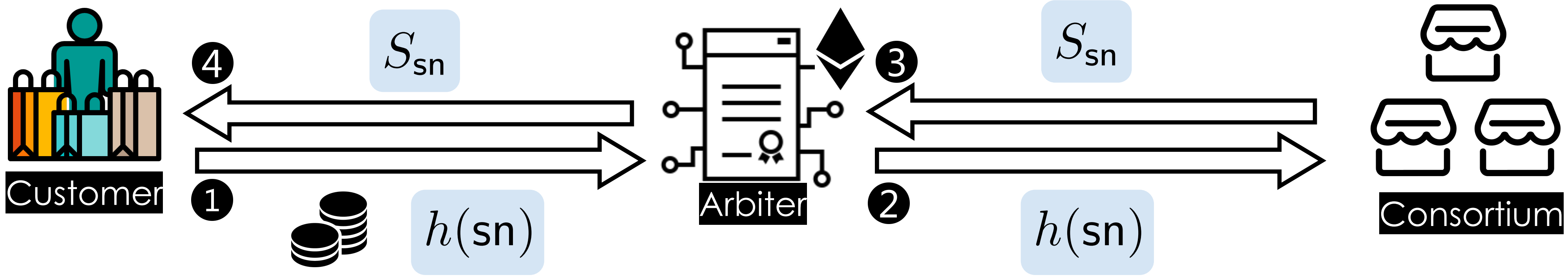
- LDSP coins are partially blind signatures from a group
- "80/20 rule": trade a bit of privacy for better efficiency

A bit more details

Withdrawal, Payment, Refund, ...

Customer's Withdrawal

- The customer funds LDSP coins via the arbiter
- The customer uploads a blinded h(sn) w/ an on-chain coin
  - h: crypto hash function, sn: (random) serial number
- The merchants *jointly* sign, *blindfolded*, on the h(sn) as S_{sn}
- The customer gets the signature S_{sn} as an LDSP coin

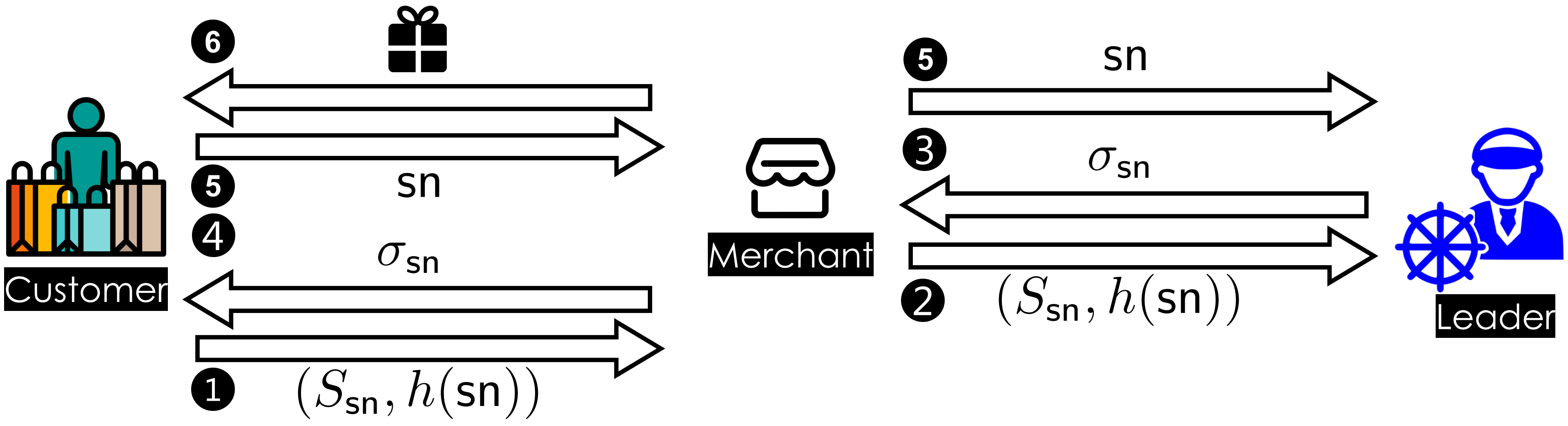


Payer Privacy

- Basically, we adopt a multi-blind signature approach
- Hide the link btw. on-chain coins & LDSP (off-chain) coins
- The customers thus hide among those spending coins from the same virtual bank

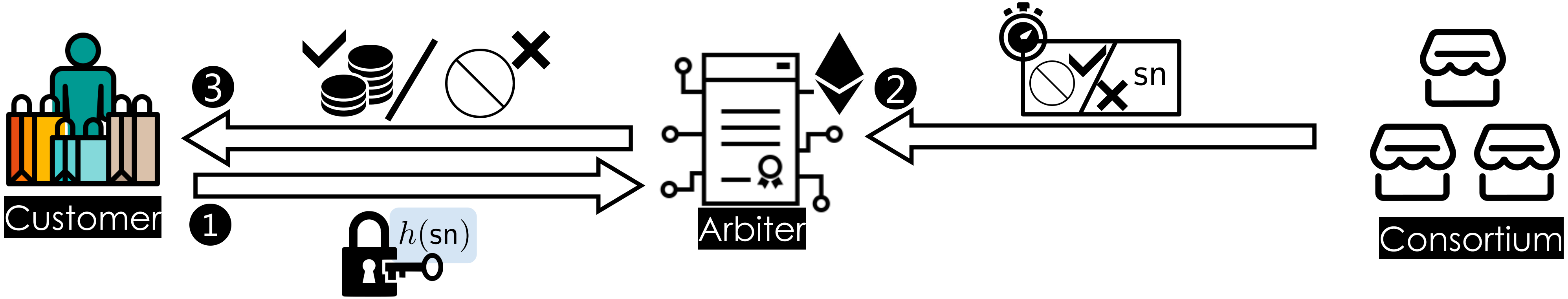
Customer's off-chain Payment

- Customer reveals the signed h(sn) to the merchant & leader
- The leader confirms it with its signature σ_{sn}
- The customer reveals sn to the merchant



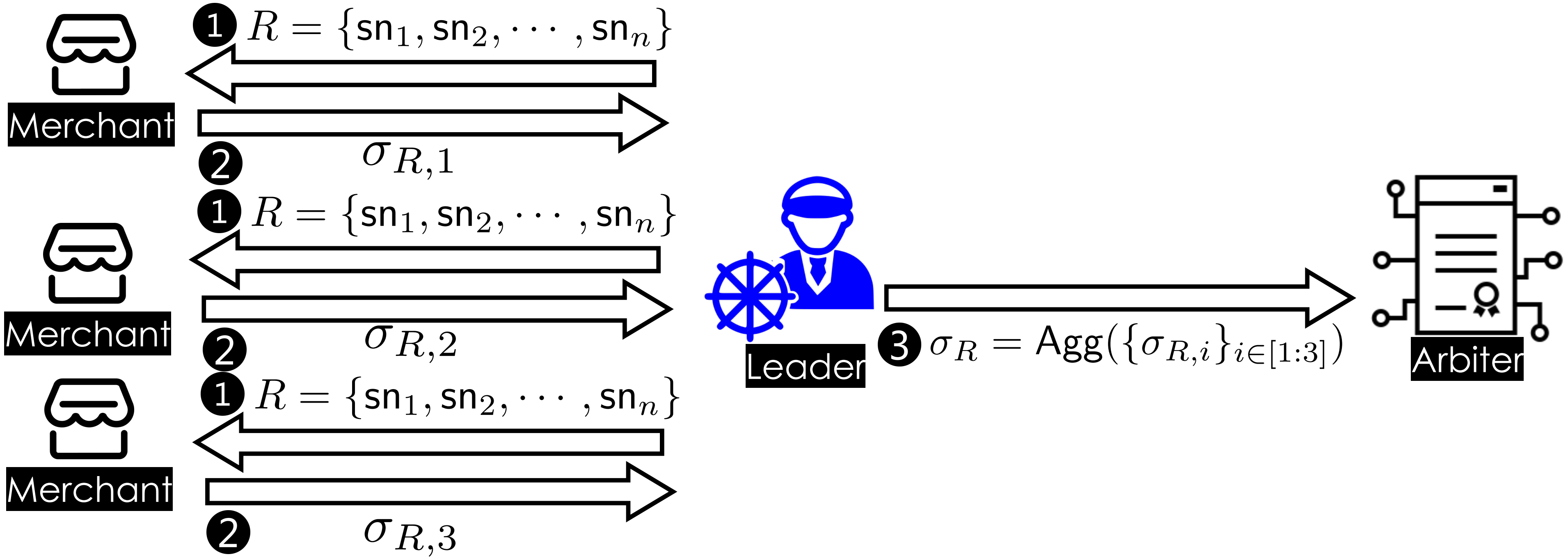
Customer's Refund

- The customer uploads the opening for $h(\text{sn})$ to the arbiter
- If sn has been spent, the merchant can reveal sn to debunk
- If no dispute, the customer gets back the on-chain coin



Merchants' Bookkeeping (& Why no Double-Spending)

- The leader releases all payment records in batch
  - which is uploaded to the arbiter after the merchants *jointly* signing on it
- The leader will be blamed if any double-spent coin is spotted
- The merchants can deposit all bookkept coins altogether later

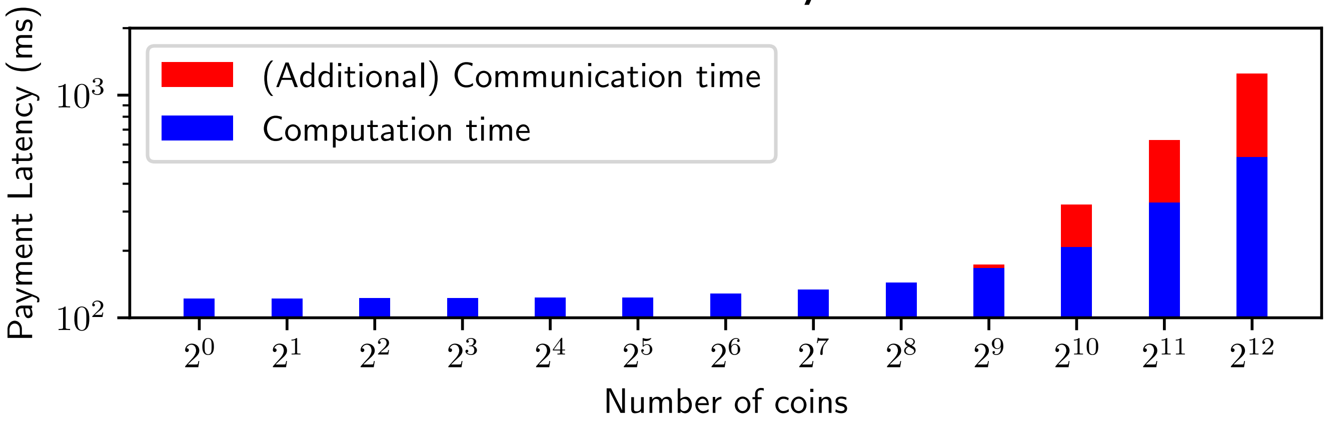


LDSP's Safety (No one loses money)

- Safety of the Customers:
  - They can always refund an unspent coin
- Safety of the Merchants:
  - For double-spending, they can blame the leader for compensation
  - No merchant can mint coin w/o the signature of all other merchants

Low-Latency Payment & Low On-Chain Cost

- Off-chain payment with < 512 coins is done in < 0.5s
  - Urban Network: 100 Mbps Bandwidth, ~20ms Latency



- Low on-chain cost

Operation	Gas (on Ethereum)	USD
Baseline	21000/tx	3.72/tx
(Batched) Withdrawal	38.36/coin	0.0068/coin
(Batched) Refund	25.76/coin	0.0046/coin

based on the average gas price and exchange rate on 1 May, 2021

Summary

- LDSP: Shopping with Cryptocurrency *Privately* and *Quickly* under "Consortium Leadership"
  - a Low Latency, Dynamic & Distributed System
  - w/ Scalable On-chain Process, & Payer Privacy
- What's more in the paper:
  - The use of round and epoch
  - Keeping a low on-chain cost via batching
  - Analysis on LDSP's safety & liveness
  - How LDSP achieves low collaterals, avoids single-point-of-failure, *etc*.
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